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Simulation of Antimicrobial Resistance Gene Fate in Narrow Grass Hedges

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SIMULATION OF ANTIMICROBIAL RESISTANCE GENE FATE IN NARROW GRASS HEDGES

by

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SIMULATION OF ANTIMICROBIAL RESISTANCE GENE FATE IN NARROW GRASS HEDGES

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Vegetative Filter Strips (VFS) are used for controlling the volume of runoff and decreasing the contaminants in runoff before entering the water bodies. Many studies investigated the role of VFS in sediment and nutrient removal, but little is known about their efficiency in the removal of emerging contaminants such as antimicrobial resistance genes (ARGs). VFSMOD was used to simulate the efficiency of VFS in this regard. The objectives of this study were to calibrate the VFSMOD with some experimental data and asses the efficiency of the model in simulating the filter behavior in removing ARGs. The tests were conducted in twenty-four 0.75 m wide by 4 m long plots which were adjacent to the narrow grass hedges. The VFS Model results met well with the experimental results and as a result the model was used for predicting filter efficiencies when the runoff data are not available. The efficiency of NGH in trapping tylosin, ermB and 16SrRNA was tested by the model. NGHs were shown to be effective in reducing tylosin and ARGs concentration. The filter length and soil type were designed by the model as 1m and sandy soil.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Agricultural runoff is one of the primary sources of nonpoint pollution to water bodies. Antibiotic usage in animal production has been in the center of attention in the study of environmental concerns since much of the antibiotics are excreted to the animal waste without any change (Bair et al., 2017). One important method of disposal of animal waste is land application which leads to the entry of both antibiotics and antibiotic resistance genes (ARGs) to soil and water bodies (Chee-Sanford et al., 2009). It is reported that runoff from agricultural fields contains conventional pollutants such as nutrients, sediment, and bacteria (Liu et al., 2008, Zuazos et al., 2009). If the runoff comes from areas receiving livestock manure, it may also contain trace organic contaminants (e.g., antibiotics and ARGs) (Soni et al., 2015).

Best Management Practices (BMPs) which are designed to control erosion and runoff include vegetative filter strips, vegetative buffers, riparian buffers and grass waterways. Vegetative filter strips (VFS) are shown to be an effective practice because of low maintenance cost and high sediment removal efficiency (Dillaha et al., 1988, Liu et al., 2008, Rahman et al., 2017). They are installed adjacent to pollutant source areas to filter sediments and other water pollutants (Liu et al., 2008) from surface of water through filtration, deposition and infiltration (Dillaha et al., 1989).

There are several parameters that affect the efficiency of VFS. A survey of literature shows that the soil slope, soil texture, infiltration properties (e.g., saturated hydraulic conductivity and porosity), filter geometry (i.e., width, length), and vegetation type are the most important factors in determination of VFS efficiency (Xiao et al., 2011, Dosskey et al., 2011 Deletic, 2001, Gilley et al., 2000, Robinson et al., 1996).

In order to simulate the contaminant transport in VFS some models have been introduced (e.g., GRASSF, VFSMOD, SEDIMETII, CREAMS, and SWAT). The Vegetative Filter Strip Model (VFSMOD) is a mechanistic model developed by Munoz-Carpena. (1999) to study hydrology and sediment transport through VFSs. The VFSMOD integrates a hydrology sub-model with a sediment filtration model to describe overland flow and infiltration. The VFSMOD can handle complex storm patterns and intensities as well as varying surface conditions within the VFS. The VFSMOD is employed to evaluate runoff and sediment transport and deposition through the filter (Munoz Carpena, R., 2010).

Many studies have evaluated the efficiency of VFS in removing sediments, nutrients, and pesticides from agricultural runoff. However, an extensive literature review reveals that there is very limited information on the ability of vegetative filter strips in removing emerging contaminants such as antibiotics or ARGs in runoff.

1-1 Objectives

The objective of this research is to predict the efficiency of the model in simulating the VFS behavior. More specifically the objectives of this study are:

(1) To calibrate the model with experimental data of a VFS in removing sediment.

(2) To predict the behavior of the VFS in removal of antimicrobial resistance genes and to determine which VFS properties most influence ARG transport through VFS.

1-2 Methodology

To meet the objectives of the thesis once a calibrated model is developed, based on data collected in a prior field study, the behavior of another contaminant would be predicted. Figure 1 presents the plan used in this study.

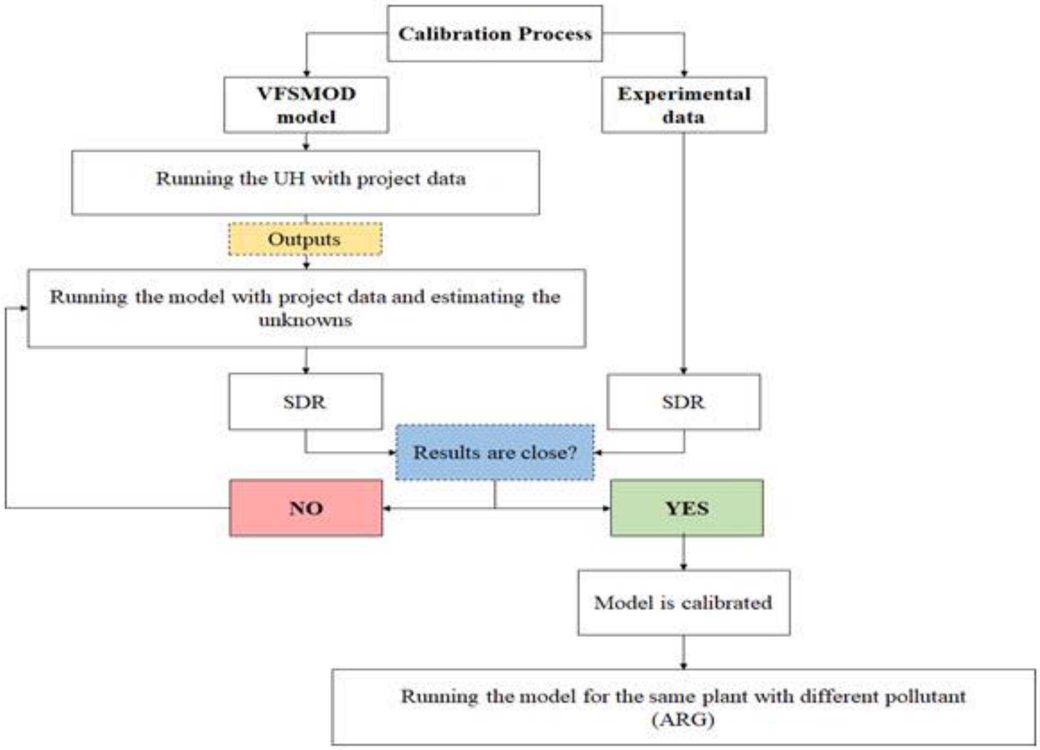

Figure 1: Simulation method of the study.

1-3 Thesis Organization

This thesis includes five chapters. After this introduction, all major components of the literature review are further introduced in the Chapter 2. Methodology, experimental data and simulation are described in Chapter 3. The results of simulation and calibration process are presented in Chapter 4. Finally, the main findings and conclusions of this study are summarized in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

2.1 VFS Definition and Application

Vegetative Filter Strips (VFS) are defined as gently sloping areas of permanent vegetation located within and between agricultural fields and the surface water bodies into which they drain (Helmers et al., 2008). VFS can also be defined as areas of vegetation designed to remove sediment and sediment bound pollutants such as phosphorus and pesticides from surface water runoff (Munoz-Carpena et al., 1999) or to prevent the movement of nonpoint source pollution to water bodies (REFERENCE). VFS retains soil in the field and prevent it from being transported, thereby minimizing erosion (Grismer et al., 2006). With proper design and maintenance, VFS can provide high pollutant removal (Khatavkar, 2015). Sudhishri et al., (2008) showed that vegetative filter strips with bunds (a construction technique to slow runoff and promote infiltration), can be used to effectively reduce runoff volume, sediment, and organic carbon losses. Table 1 summarizes the VFS efficiency in removing pollutants from cropland and feedlot runoff reported in the literature.

Table 1: VFS efficiency in removing pollutants in several states.

Study	Pollutant	Removal Efficiency	Location
Dillaha et al. (1989)	Sediment P (total) N (total)	97.5% 87% 61%	Virginia
Muñoz-Carpena et al. (1999)	Sediment	93%	North Carolina
Robinson et al., (1996)	Sediment	85%	Iowa

Table1: VFS efficiency in removing pollutants in several states (Cont.).

Parsons et al. (1991)	P total N total	46% 50%	North Carolina
Moore et al. (1981)	Herbicide (Atrazine)	44-100%	Mississippi
Barfield et al. (1994)	Sediment NH4-N	97% 92%	Kentucky

Note: Reprinted from "Vegetative Filter Strips; A Best Management Practice for Controlling Nonpoint Source Pollution" by Wu et al., (2015).

Figure 2 shows a typical VFS which is located near an agricultural area. After rainfall, the runoff moves through the VFS and at the same time contaminants are removed through different processes such as infiltration and attachment to vegetation.

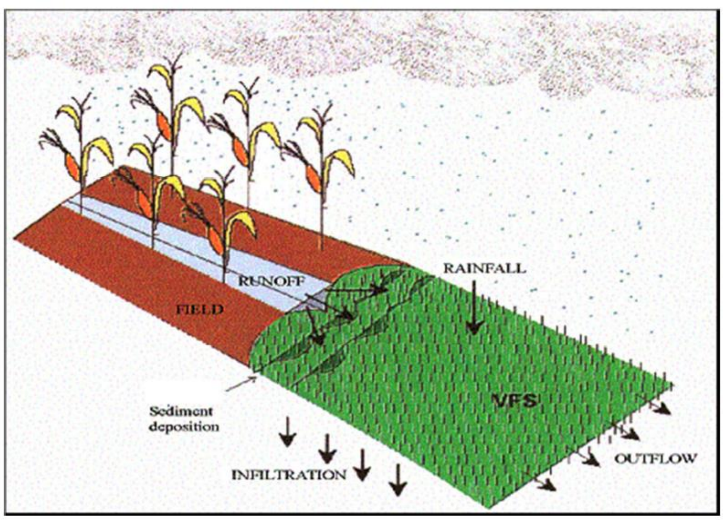

Figure 2: Typical VFS for an agricultural area (Source: http://abe.ufl.edu/carpena/vfsmod).

2.2 Physical Processes in VFS

Several studies have shown that the main processes for contaminant removal in VFS are infiltration, deposition, sorption and degradation (Krutz et al., 2005; Zhang et al., 2010). The VFS system properties and the pollutant flow are factors that influence the relative importance of these processes in a given system (Cheg et al., 2016).

Infiltration is the main mechanism for soluble contaminants removal, but it also plays a role in suspended particle removal (Fox et al., 2005). It leads to a decrease in sediment transport capacity and enhance in sedimentation because of decreasing the discharge and velocity of overland flow. Infiltration occurs when the seasonal high groundwater table and the bedrock are lower than 90cm and 60cm from the bottom of VFSs respectively (Cahill et al., 2008). Slowing the flow velocity provides greater time for infiltration of the water into the soil. Proper design and maintenance provide good sediment and contaminant removal.

Barfield et al. (1979) have shown that when the transport capacity is less than the inflow sediment loads, the most likely process for contaminant removal would be sediment deposition. When runoff enters the filter strip, its velocity decreases and sediment begins to settle. Large, sand- and silt-sized particles, and soil aggregates settle from the runoff within a relatively short distance into the filter (Leeds et al., 2013). Smaller fine particles (e.g., clay); require a longer distance to be settled out. As a result, the chance of deposition for small size particles is lower for larger size particles. For pesticides, an important mechanism of retention is sorption to the soil surface and vegetation leaves (Chen et al., 2016). If the pesticides are trapped in the filter, they would degrade, and their degradation would increase with higher microbial activities (Ktutz et al., 2005).

2.3 Types of Vegetative Filters Strips

Vegetative barriers (VB) are strips that are located downslope on croplands near surface water and usually include densely growing plants. Narrow Grass Hedges (NGHs) are one type of VB and are made up of stiff stemmed grass strips that are about 1.5 m wide and placed at short intervals (Soni et al., 2015). The difference between filter strips and barriers is that the filters are wider and established between agricultural fields and streams. They reduce nonpoint source pollutants, sediment and nutrients while the flow is shallow. One advantage of barriers is that their erect stiff stems cause great hydraulic resistance to runoff and so they can control concentrated flows (Dunn and Dabney, 1996).

VFS are divided into three different categories based on their design methods: (1) Basic VFS, (2) Compost amended VFS (CAVFS), and (3) Narrow area VFS. For flow paths less than 9 m, the narrow area is the simplest methods to be used while for flow paths over 9 m, either the basic VFS or CAVFS are used. The removal mechanisms include sedimentation, infiltration, and entrapment by the vegetation. Furthermore, the removal efficiency of vegetative filter strips depends upon variables including length of filter strip, vegetation type, soil type and slope (Goel et al., 2004). Table 2 shows adopted total suspended solids (TSS) removal rates for different vegetated filter strips. Adopted TSS is based on the weighted average rates when there is a mixture of vegetation (NJ Stormwater BMP Manual).

Table 2: Adopted TSS removal rates for vegetated filter strips.

Vegetated Cover	**Adopted TSS Removal Rate**	**Source**
Turf Grass	60%	NJ Stormwater, BMP Manual
Native Grasses, Meadow, and Planted Woods	70%	NJ Stormwater, BMP Manual
Indigenous woods	80%	NJ Stormwater, BMP Manual

The vegetation of VFS consist of natural and established vegetation communities. The filters range from turf grass to woody species with native grasses and shrubs. The strips can be easily incorporated into landscaping plans since the vegetation community is suitable for green design. As a result, they can accent adjacent natural areas or provide visual buffers within developed areas (www.leg.state.mn.us, 2018). VFSs are most effective if the vegetation is healthy and dense. Grasses are most effective in shorter filter strips while woody species may be suitable for longer filter strips.

VFS are used to reduce surface water contamination caused by agricultural nonpoint source (NPS). By moving through the VFS, the water has more time to penetrate and incorporate the pollutants in the soil and thus prevent off-site movement (Leed et al., 2013). Changes in flow hydraulics which is caused by VFS, reduce runoff speed and increase water infiltration. The filter enhances sediment deposition and filtration by vegetation, pollutant adsorption into the soil and uptake of soluble pollutants by plants (Abu zreig et al., 2011).

2-3-1 Grass Filter Strips (GFS)

In order to protect water quality, grass filter strips should be planted between the fields and surface waters such as lakes, streams and rivers. GFS not only decreases the velocity of runoff but also removes the pollutants such as sediments, nutrients and pesticides through trapping and filtering before reaching to the surface waters. It should be noted that planting GFS around drainage tile inlets can be also employed for the same purposes (Minnesota practice standard-Filter Strips).

2-3-2 Vegetative Buffer Strips (VBS)

VBS are widely used as a conservation measure to reduce fluxes of sediments and associated pollutants from overland flow in catchments. The buffers reduce sediment and associated pollutants through a combination of settling, infiltration and adhesion processes (Newham et al., 2005).

The type and width of vegetation used in buffer strips can affect the efficiency of sediment trapping. Buffer hedges usually comprise of tall and erect grass strips. Their width is commonly less than 1 m and decrease fluxes because of the settling of sediments. The settling of particulate-sorbed nutrients such as nitrogen and phosphorus leads to reduction in pollutant loads. This type of hedge usually requires vegetation that has a dense upright growth pattern with strong rooting systems. Vetiver and switchgrass that can withstand high flow depths up to 600 mm can be considered as good choices for VBS filters (Truong, 1999; Metcalf et al., 2003; Blanco-Canqui et al., 2004a). However, Hussein et al. (2006)

stated that the shorter grasses may be as effective as tall grasses only in low flow depths and in higher flows that can be easily overtopped (Hussein et al. 2006).

2.4 Design Variables for VFS

The United States Environmental Protection Agency (EPA) provides guidance on some key elements such as slope, site preparation, soil treatment, filter width, type of vegetation, placement, maintenance, and monitoring in designing VFS (EPA, 2018)

Vegetation at the downstream edge of disturbed areas effectively reduce runoff volume and peak velocity due to the filter's hydraulic roughness and subsequent augmentation of infiltration (Munoz-Carpena, et al., 1999). However, Wilson (1967) claimed that the decreasing flow volume and velocity translates into sediment deposition in the filter as a result of a decrease in transport capacity and the filter is not submerged if the flow is shallow and uniform.

Wu et al. (2015) stated that sturdy, tall, perennial native grass species are generally the best choices for removing sediment. Rahman et al. (2011) showed that dense and standing vegetation is required for effective filtration. In addition, Barfield et al. (1979) and Dillaha et al. (1986) reported that grass filter strips have high sediment trapping efficiencies. Vegetation increases surface roughness and as a result surface runoff velocity reduces, thereby deposition of sediment increases, and transport of particulate-bound nutrients decrease. When nutrients are released and transported from animal feeding operations, they may be taken up by vegetation and then removed as biomass. Vegetation types may also affect the canopy density, root distribution and nutrient uptake (Rahman et al., 2011). Kizil (2002) has shown that the type of grass, i.e., were bluegrass, dense grass and short grass with Manning coefficients equal to 0.45, 0.24 and 0.15 respectively, did not affect the sediment trapping efficiency.

Dillaha et al. (1989) and Parsons et al. (1991) showed that the filter length controls sediment trapping up to an optimum level which depends on the source area and hydraulic characteristics of the strip. Glismer et al. (2006) showed that increasing the width of the strip increases the effectiveness of VFS by increasing the contact time between runoff water and vegetation in the strip. Table 3 and Table 4 show the minimum width for vegetative filter strip and examples of pollutant removal efficiency for VFS respectively.

Table 3: Minimum width for vegetative filter strips

Slope	Minimum width of the buffer strip	Source
1-3%	7.6m	Grismer et al., 2006
4-7%	10.7 m	Grismer et al., 2006
8-10%	15.24 m	Grismer et al., 2006

Table 4: Removal efficiency of VFS from different studies.

Study	Filter type used	Nutrient source	Plot length (m)	Pollutant	Removal Efficiency%
Cole et al. (1997)	Bermudagrass buffer strip	cropland runoff	4.8	Chlorpyrifos dicamba 2,4-D mecroprop	62-99 90-100 89-98 89-95
Parsons et al. (1992)	Bermudagrass-crabgrass mixture	cropland runoff	4.3-5.3	P (total) N (total)	26 50
Barfield et al. (1992)	Bluegrass and fescue sod (9% slope)	cropland runoff	4.6 9.1 13.7	NH4-N Atrazine NH4-N Atrazine NH4-N Atrazine	92 93 100 100 97 98
Young et al. (1980)	Corn-oat or orchardgrass mixture (4% slope)	feedlot	13.7	P (total) N (total)	88 87
Doyle et al. (1977)	Fescue (10% slope)	Dairy Waste on Silt loam Soil	1.5 4.0	P dissolved NO3 P dissolved NO3	8 57 62 68
Dillaha et al. (1988)	Orchardgrass (5-16% slope)	Simulated feedlot	4.6 9.1	P (total) N (total) P (total) N (total)	39 43 52 52

Table 4: Removal efficiency of VFS from different studies (Cont.).

Study	Filter type used	Nutrient source	Plot length (m)	Pollutant	Removal Efficiency%
Dillaha et al. (1988)	Orchardgrass (5-16% slope)	Cropland runoff	4.6 9.1	P (total) N (total) P (total) N (total)	75 61 87 61
Patty et al. (1997)	Ryegrass	Cropland runoff	6,12, and 18	Suspended solids Atrazine Isoproturon Diflufenican NO3 P(soluble)	87-100 44-100 99 97 47-100 22-89
Young et al. (1980)	Sorghum-Sudan-grass mix (4% slope)	feedlot	13.7	P(total) N(total)	81 84
Moored et al. (2001)	Vegetated drain age ditch	Simulated runoff	4	Atrazine pyrethroid	98 100

Note: Reprinted from “Vegetative Filter Strips for Nonpoint Source Pollution Control in Agriculture”, by Grimser et al., 2006.

Generally, wider filter strips perform better than narrower ones. The filter strip width should be wide enough to effectively trap clay-sized particles which require the lowest velocities through the filter. A recent Field Office Technical Guide (NRCS, 2015) indicates that 6 m is the minimum flow length (width) through the filter strip. The filter width is the most important factor that affects phosphorous trapping in vegetated filter strips (Abu Zreig et al., 2001). The average phosphorus trapping efficiency of 61% is reported by Abu Zreig et al., (2002) (31% in a 2 m filter to 89% in a 15 m filter). Their results show that increasing the filter length beyond 15 m is ineffective in enhancing sediment removal while it is expected to increase the removal of phosphorus.

Vegetation type is another important factor. Generally, dense, standing vegetation is required for efficient filtration effect. Vegetation increases surface roughness, resulting in reduced surface runoff velocity, thereby increasing deposition of sediment and decreasing transport of particulate-bound nutrients. Sediment and some nutrients are adsorbed on leaves and stems. Nutrient uptake by vegetation and its removal as biomass is also an important way to manage nutrients, which are released and transported from the concentrated animal feeding operations. Canopy density, root distribution, and nutrient uptake are all affected by vegetation types (Rahman et al., 2011). Plant density is also vital factor in slowing runoff and allowing the sediments to settle out. Cahill et al. (2008) reported that densely vegetated VFSs control weeds and lead to maximum runoff treatment.

VFS works satisfactory on slopes less than 4% (between 0.5 to 4%) and VFS are not recommended for the slopes greater than 15% (Glismer et al., 2006, Wei et al., 2015). Steep slopes decrease the amount of infiltration and pollutant removal and require larger facilities (LIDMM, 2008).

2.5 Contaminant Removal in VFS

Vegetative filter strips can remove different contaminants such as nutrients, herbicides (Caron et al., 2012), sediments, fecal bacteria, and some antimicrobials like tylosin and its resistance genes (Soni et al., 2015). In the following sections the contaminants removed by VFS are mentioned.

2.5.1 Sediment

Using VFS can lead to reduction of diffuse fluxes of sediments. Hussein et al. (2005) conducted a study on sediment retention by narrow grass hedges under subcritical flow conditions. They found that the type of flow affects the size distribution as well as the amount and efficiency of sediment deposition in front of vetiver hedges. In addition, they reported that the sediment concentration remains fairly constant with time, however, it depends on soil types. Sediment removal efficiency was measured in different studies for many areas and reported in a range of 85% to 97.5% (Dillaha et al., 1989; Robinson et al., 1994; Schmitt et al., 1991; Munoz-Carpena et al., 1999).

2.5.2 Nutrients

Gilley et al. (2011) examined the effectiveness of a narrow grass hedge in reducing runoff nutrient load following manure application. They showed that stiff stemmed grass hedges planted at selected downslope intervals can significantly reduce the transport of nutrients in runoff from areas with a range of soil nutrient values. In addition, they found that NGHs significantly reduce the mean load of dissolved or soluble phosphorus (DP), particulate phosphorus (PP) and total phosphorus (TP), ammonium nitrogen (NH_4-N), and total nitrogen (TN) in runoff. Manure application rate influenced runoff loads of DP, PP and TP. A range of 50 to 85% trapping efficiency for sediments and nutrients adsorbed to sediments has been reported (Young et al., 1980; Daniels and Gilliam, 1989; Dillaha et al., 1989; Magette et al., 1989), however, the lower efficiency was reported for dissolved nutrients by Dillaha et al. (1989) and Magette et al. (1989). Rahman et al. (2012) evaluated the performance of a VFS at down slope end of a beef feedlot under North Dakota climatic conditions and analyzed the runoff samples for solids, nutrients, pH and conductivity using standard methods. They concluded that a vegetative filter strip without a settling basin was effective in reducing solids and nutrients concentrations from feedlot runoff water, except for soluble nutrients. They observed a 29.9% and 19.8% concentration reduction in total phosphorus and orthophosphorus, respectively.

2.5 3 Pesticides and Trace Organics Contaminants

VFS can remove not only sediment associated contaminants but also some dissolved contaminants through filtration, deposition, infiltration, adsorption, absorption decomposition and plant uptake. When pesticide is in dissolved phase, they could be removed from surface runoff through infiltration into the soil, however, when pesticides are sediment bound they can settle out by sedimentation (Chen et al., 2016). Although relatively small herbicide loads are carried by surface runoff water in relation to the amount applied to a cultivated field (from less than 0.5% up to 5%), their residues lead to serious environmental risks. Cardoso et al. (2012) showed that high bacterial retention capacity in vegetated plots compared with very low bacterial retention in bare plots. Soni et al. (2015) demonstrated that the role of NGHs in decreasing the level of antimicrobials and ARGs in agricultural runoff. NGHs lowered tylosin loading in runoff by more than an order of magnitude. The reason might be related to the adsorption of tylosin within the NGH system.

Soni et al. (2015) conducted a field experiment to test the effect of three factors; i.e., manure amendment, narrow grass hedges (NGHs) and rainfall events, on antimicrobial and ARG movement in runoff. They reported that manure amendment leads to the presence of the antimicrobial tylosin ($p<0.0001$) and tylosin resistance gene *erm*(B) ($p<0.0001$) in runoff. In addition, the results showed that NHHs could reduce tylosin ($p<0.0001$) and *erm*(B) ($p<0.0347$) in runoff. Based on the results of this study, NGHs could be considered as a best management practice for controlling antimicrobials and ARGs transport in agricultural runoff. Table 5 shows mass loadings of tylosin in runoff from the amended plots during three rainfall occurrences.

Table 5: Mass loading of tylosin exported in runoff with and without NGH during three rainfall occurrences.

Rainfall occurrence	**Tylosin (μg m^{-2})**	
	Without narrow Grass hedge	**With narrow Grass hedge**
1	48.47±23.25	2.74±1.77
2	33.69±13.41	3.61±3.29
3	20.50±12.63	2.48±0.59
Sum	102.65	8.87
Fraction from event 1	0.47	0.31

Note: Reprinted from "Narrow Grass Hedge Reduce Tylosin and Associated Antimicrobial Resistance Gene in Agricultural Runoff" by Soni et al., 2015.

2.6 Numerical Models for Vegetative Filter Strips

In order to simulate VFS efficiency in pollution removal, one of the primary models was GRASSF developed by researchers at the University of Kentucky (Munoz et al., 2010). GRASSF is a physical based model which considers a number of important field parameters that affect the sediment transport and deposition through filter. These parameters include sediment type and concentration, vegetation type, slope and length of the filter. However, the model is based on lab conditions. As a result, the GRASSF model was modified by Wilson et al., (1981) and incorporated into SEDIMOT II, which is a hydrology and sedimentology watershed model. However, this model does not include the time dependent infiltration and changes in flow originated from sediment deposition during the storm event.

CREAMS model is the next model proposed by Knisel (Knisel, 1980). This model was employed by several researchers to evaluate the performance of VFS (Munoz et al., 1999). CREAMS is a field scale model for chemicals, runoff and erosion from agricultural management systems and is used for evaluating buffer strips (Gharabaghi et al. 2001). However, Dillaha and Hayes (1991) pointed out that CREAMS does not simulate the principal physical processes (e.g., filtration and sorption) affecting transport in VFS (Munoz-Carpena, et al., 1999). In addition, the hydrology component does not consider the runoff volume changes or peak rates from the site which are caused by the filter.

Parajuli et al. (2008) evaluated the efficiency of VFS in decreasing fecal bacteria and sediments in a watershed using the Soil and Water Assessment Tool (SWAT). They used the SWAT model to compare the effectiveness of a target vs a random approach in reducing pollutant. The effectiveness of VFS length was tested in removing fecal bacteria concentration and the SWAT model demonstrated to be able in evaluating the VFS effectiveness.

VFSMOD is a field scale, mechanistic, storm-based model developed by Munoz-Carpena et al. (1999) based on readily available algorithms and equations to generate inflow hydrographs and hyetographs for many expected source area conditions (Suwandono et al., 1999). Sediment transport and deposition through VFS are affected by some important parameters such as sediment type and concentration, slope and length of the filter. The model considers all these parameters as inputs to calculate the resulting outflow, infiltration, and sediment trapping efficiency (Munoz-Carpena, et al 1999). VFSMOD is a desktop-based model and requires input data considering various conditions of upland field and vegetative filter strip.

Several studies demonstrated the ability of VFSMOD to predict reductions in runoff volume and sediment concentration moving through the filters (Abu-Zreig, 2001; Abu-Zreig et al., 2001; Gharabaghi et al., 2000). For instance, Gharabaghi et al., (2000) evaluated VFSMOD model by considering a foundation of VFS hydrological, sedimentological and chemical parameters. The model showed a good potential in predicting sediment removal efficiency of VFS. More recently, Abu-Zreig et al. (2001) evaluated the efficiency of VFS in sediment removal. Application of the model to experimental data was satisfactory when instead of the total filter width, the actual flow widths were used in the model.

CHAPTER 3: METHODOLOGY, EXPERIMENTAL DATA AND SIMULATION

3.1 Methodology

The simulation of VFS is based on the VFSMOD-W approach introduced by Rafael Munoz-Carpona. An input preparation utility (UH) creates the model inputs and uses an NRCS design storm to produce the outputs. The input files for VFSMOD are produced based on Natural Resources Conservation Service (NRCS) curve number, unit hydrograph and Modified Universal Soil Loss Equation (MUSLE). The UH outputs are field inflow hydrograph, field sediment inflow and characteristics. These outputs act as the inputs for the VFSMOD model. VFSMOD provides an accurate description of the flow conditions from the hydrology submodel whereas changes in surface conditions due to sediment deposition during the event are obtained from the sediment filtration (Munoz et al., 1999). However for solute transport and multi reactive transport the model has not defined yet a module.

3.2 Experimental Data

The experimental data were obtained from a prior study conducted at the University of University of Nebraska (UNL) Rogers Memorial Farm which is located 18 km east of Lincoln, Nebraska. Three treatment factors were tested in the experiments including manure amendment, narrow grass hedges and rainfall events. The narrow grass hedges at Rogers Memorial Farm were originally established in 1998. In this field study, twenty-four plots with dimension of 0.75 m (width) by 4.0 m (length) were built on an area with an average 3% slope. The 4.0 m plot dimension was parallel to the slope and in direction of overland flow. The schematic experimental design of this study is shown in Figure 3.

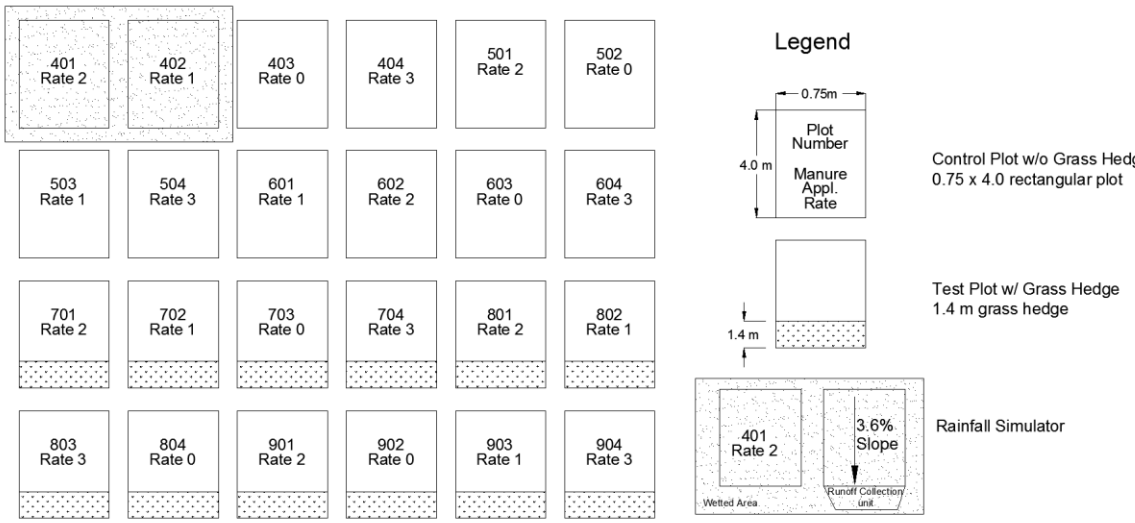

Figure 3: Schematic showing the plot layout, hedge and no hedge treatments, and nitrogen application rates based on 3-year corn N requirements (Soni et al., 2015).

Field tests were conducted from July 6 to July 28, 2008. Swine slurry was collected from the United States Department of Agriculture (USDA) Meat Animal Research Center near Clay Center, Nebraska before field application. The rainfall simulation tests were conducted after slurry application. Manure application rate was based on the 3-year N requirements for corn. Water used in the rainfall simulation tests was collected from an irrigation well. Each rainfall event lasted for 30 min with an intensity of 70 mm/hr. Two additional tests were conducted at approximately 24-hour intervals to evaluate the role of different runoff rates. Two composite runoff samples were collected and stored at -20 ^{0}C, one for water quality analysis and the other for sediment analysis. Soil samples were selected only from the plots without the NGHs since the presence of the NGHs had no effect on the fate of contaminants.

3.2.1 Antimicrobial Analysis of Runoff and Soil Samples

Microbial analysis performed on each runoff sample was based on solid phase extraction (SPE) (Joy et al., 2013). The average of eight replicates was used to measure ARG recovery values from runoff determination by using of 4 ngL^{-1} fortified reagent water and results are shown in Table 6.

Table 6: Concentration of Tylosin and its ARGs in runoff.

Tylosin µg/l	**erm(B) Copies/ml runoff**	**16S rRNA gene Copies/ml runoff**	**Source**
0.12	1.09×10^{4}	3.65×10^{6}	Soni et al.,2015

The recovery of tylosin was determined by solvent extraction method in soil samples and the measured percentages using eight replicates are included in Table 7:

3.4 UH Utility Inputs

The UH inputs and definition of each parameter are shown in Table 7. It should be noted that the value for the experimental data is for a plot with NGH (plot 701, rate 2, run2) 2008 study. The plot belongs to the second rainfall simulation experiment (day 2) and manure was applied meeting the nitrogen requirement rate 2 for corn. The annual yield of corn was expected 9.4 Mg ha $^{-1}$ and N requirement for rate 2 would be 151 kg N. ha^{-1}. yr^{-1}.

Table 7: UH input parameters.

Utility	Parameter	Value	Source
Rainfall Event and Runoff	Rainfall (mm)	177.3	Experimental data
	Storm Duration (h)	0.5	Experimental data
	Curve Number	85	Model manual
	Storm Type	II	Model manual
Source Area	Length (m) along the slope	4	Experimental data
	Slope as a fraction	0.036	Experimental data
	Area (ha)	$3E^{-4}$	Experimental data
Erosion Parameter	Soil Erodibility (K), (t.ha.h)/(ha.MJ.mm)	0.04260	Model manual
	Percent organic matter	4	Experimental data
	Crop Factor (c)	8	Model manual
	Soil Type	Silty clay loam	Experimental data
	dp particle Class Diameter (cm)	0.04	Model manual
	Practice Factor (P)	0.5	Model manual

The rainfall is the total rainfall for each plot measured in mm and storm duration is the duration of rainfall which is 30 min. These parameters were measured in the 2008 field study and published in Soni et al. (2015). The curve number (NRCS number for the source area) is between 0 to 100 and based on the VFSMOD manual, the curve number could be estimated for different cover types, treatment and hydrologic conditions. First the hydrologic soil group is identified in the manual and divided based on the soil type and its impact on runoff potential. Considering medium runoff potential (shallow sands or clay soils), B or C soil group was chosen. For fallow crop type and crop residue cover, which were the case during the rainfall simulation experiments, the curve number will vary between 90 and 85.

Storm type, which is the type of rainfall event, is selected as type II which is associated with the most areas of the US except areas which are specified by type I, IA and III. Type I is related to the coastal side of the Sierra Nevada and the Cascade Mountains of Oregon, Washington and northern California and the coastal regions of Alaska. Type III is for storms along the Gulf coast, southern Florida and coastal areas of the eastern US. As reported in Soni et al. (2015), the length along the slope is 4 m and the slope is 3.6%. The area was calculated as 0.0003 ha.

Soil erodibility factor (K) is the MUSLE soil erodibility factor which is calculated using Equation 1:

$$K=0.1317[TF(12-OM)+SF+PF] \qquad \textbf{Equation 1}$$

Where K, TF, OM, SF, PF is soil erodibility factor in (Kg/N).(h/m^2), texture factor, percentage of organic matter, structure factor and (permeability factor), respectively. These factors are selected based on the type of soil. Table 8 shows erosion parameters needed for Equation 1 based on silty clay loam soil.

Table 8: Erosion parameters for silty clay loam soil.

Soil Type	**Silty Clay Loam**	**Source**
TF	0.02606	Model manual
SF	0.06500	Model manual
PF (chosen based on the slope)	0.05000	Model manual
Percentage of OM	4%	Experimental data
K (Kg/N)×(h/m^2)	0.04260	Calculated

Gilley et al. (2011) reported that the soil contains 4% organic matter and the soil type is silty clay loam. d_p or particle class diameter is between 300 to 4600 μm for silty clay loam. The practice factor is 0.5 based on the land slope of 0.036 and crop factor is in the range of 5 to 8 based on the crop sequence, cover and management. Table 9 includes K_s, S_{av} and porosity for different types of soil.

Table 9: Ks, Sav and porosity for different soil types.

Soil Texture (USDA)	K_s (m/s)×10^{-6}	S_{av}(m)	Porosity = Θ_s (m^3/m^3)	Source
Clay	0.167[a] 0.306[b]	0.0639-1.565[a] (0.3163)[a]	0.475(0.427-0.523)[a] 0.50[b]	Model manual
Sandy-Clay	0.333[a] 0.389[b]	0.0408-1.402[a] (0.2390)[a]	0.430(0.370-0.490)[a] 0.44[b]	Model manual
Clay-Loam	0.556[a] 1.194[b]	0.0479-0.9110[a] (0.2088)[a]	0464(0.409-0.519)[a] 0.48[b]	Model manual
Silty-Clay	0.278[a] 1.028[b]	0.0613-1.394[a] (0.2922)[a]	0.479(0.425-0.533)[a] 0.52[b]	Model manual
Silty-Clay-Loam	0.556[a] 1.583[b]	0.0567-1.315[a] (0.2730)[a]	0.471(0.418-0.524)[a] 0.51[b]	
Sandy-Clay-Loam	0.833[a] 3.139[b]	0.0442-1.080[a] (0.2185)[a]	0.398(0.332-0.464)[a] 0.43[b]	Model manual
Loam	3.67[a] 4.306[b]	0.0133-0.5938[a] (0.0889)[a]	0.463(0.375-0.551)[a] 0.46[b]	Model manual
Silt-Loam	1.89[a] 4.472[b]	0.0292-0.9539[a] (0.1668)[a]	0.501(0.420-0.582)[a] 0.48[b]	Model manual
Sandy-Loam	6.06[a] 13.93[b]	0.0267-0.4547[a] (0.1101)[a]	0.453(0.351-0.555)[a] 0.45[b]	Model manual
Loamy-Sand	16.6[a] 26.86[b]	0.0135-0.2794[a] (0.0613)[a]	0.437(0.363-0.506)[a] 0.46[b]	Model manual
Sand	65.4[a] 30.03[b]	0.0097-0.2536[a] (0.0495)[a]	0.437(0.374-0.500)[a] 0.46[b]	Model manual

[a] Rawls and Brakensiek (1983); [b] Saxton and Rawls (2006).

Figure 4 and Figure 5 show the outputs of the UH as rainfall hyetograph and runoff hydrograph which would be used as inputs for the VFSMOD.

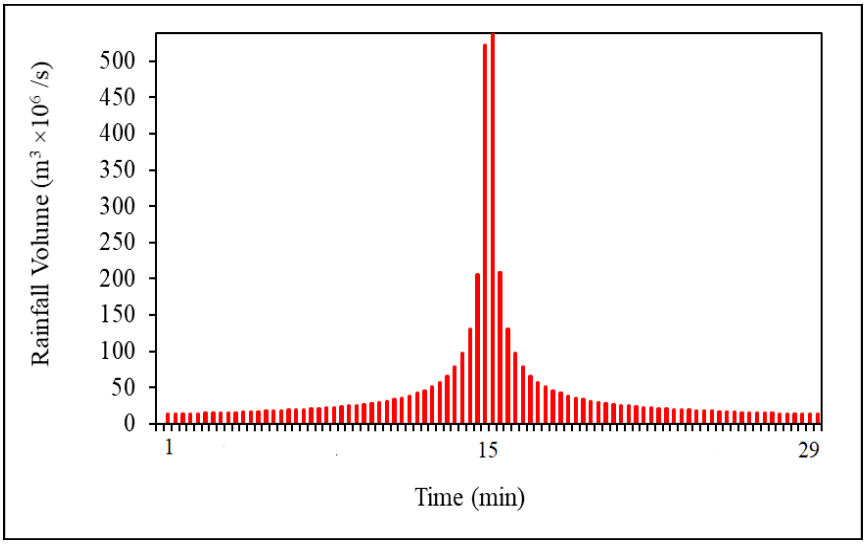

Figure 4: Rainfall Hyetograph, plot 701/Run2/Rate2.

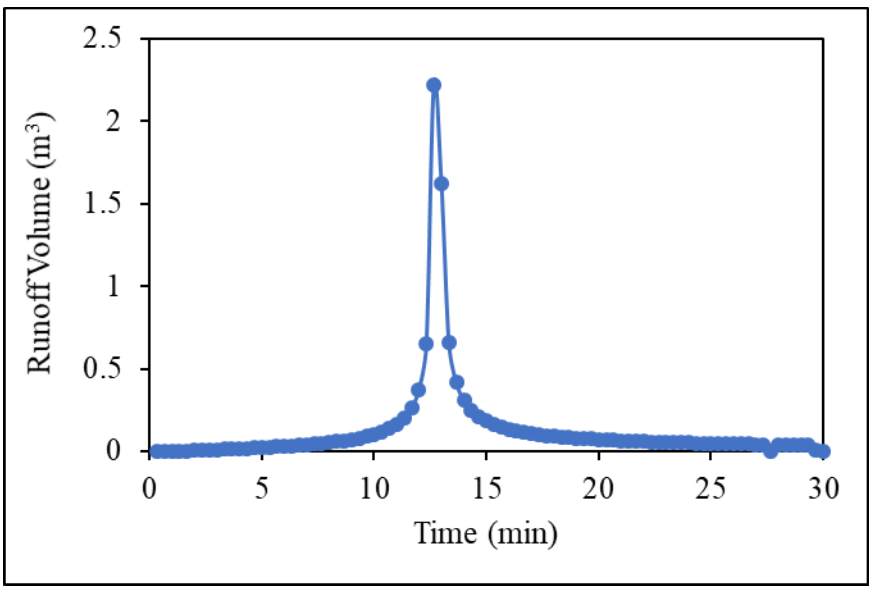

Figure 5: Runoff Hydrograph, plot 701/Run2/Rate2.

3.5 VFS Project window Inputs

The required inputs for VFSMOD are obtained based on six different project files containing a keyword (i.e., ikw, iso, isd) for the related position as described in the following sections.

Overland flow (ikw)

Overland flow (ikw) project file is related to the source area which in this project means the amended plot area. Model format of overland flow parameters including the number of nodes and the time factor are described in Table 10.

Table 10: Variables of overland flow (ikw).

LABLE	A label (max 50 characters) to identify the program run	VFS-Modelling	Source
FWIDTH	Width of the plot, m	0.75	Soni et al. 2015
VL	Length of the plot, m	1	Soni et al. 2015
N	Number of nodes in the domain, must be an odd number for a quadratic finite element solution	57	Model default
THETAW	Time weight factor for the Crank-Nicholson solution, 0.5 recommended	0.5	Model default
CR	Courant number for the calculation of time step from 0.5-0.8 recommended	0.8	Model default
MAXITER	Integer, Maximum number of iterations allowed in the picard loop	350	Model default
NPOL	Integer, number of nodal points over each element, (polynomial degree+1)	3	Model default
IELOUT	(integer) flag to output elemental information (1) or not (0)	1	Model default
KPG	(integer) number of segments with different surface properties (slope or roughness)	1	Model default
SX(I)	(real) X distance from the beginning on the filter, in which the segment of uniform surface properties ends (m)	4	Model default
RNA	Manning's roughness for each segment (s.m-1/3)	0.3	Model default
SOA(I)	slope at each segment (unit fraction, i.e. no units)	0.036	Model default
IWQ	water quality/transport problem selection flag) 0 or not present do not run problem; 1 run problem- *.iwq file required	0	Model default

- ***VFS infiltration soil properties (iso)***

VFS infiltration soil properties (iso) folder includes infiltration soil properties which are described in Table 11. These parameters are important in calculating infiltration volume.

Table 11: Input parameters of infiltration soil properties.

Input Parameter	Description	Value	Source
VKS	Saturated hydraulic conductivity, Ks (m/s) × 10^{-6}	0.55[a] 1.583[b]	Model manual
S_{av}	Green Amp's average suction at wet front (m)	0.0567-1.315[a] (0.2730)[b]	Model manual
OS	Saturated soil-water content, Θ_s (m^3/m^3)	0.471(0.418-0.524)[a] 0.51[b]	Model manual
OI	Initial soil water content, Θ_i (m^3/m^3)	0.125	Model manual
SM	maximum surface storage (m)	0	Model default
SCHK	relative distance from the upper filter edge where the check for ponding conditions is made (i.e. 1= end filter, 0.5= mid point, 0= beginning)	0	Model default

[a] Rawls and Brakensiek (1983); [b] Saxton and Rawls (2006) assuming MO: 2.5%.

- ***Buffer Vegetation Properties (igr)***

Buffer vegetation properties used in VFS model are shown in Table 12. These items specify the properties of the NGH vegetation such as the distance between hedges, and height of grass.

Table 12: Buffer vegetation properties.

Properties	Value	Unit	Source
Spacing for grass stems, SS	2.2	cm	Experimental data
Height of grass	15	cm	Experimental data
Roughness-Grass Manning's n- VN	0.24	(s/cm$^{1/3}$)	Model manual

- ***Incoming Sediment Characteristics (isd)***

This project file needs the incoming flow sediment concentration, sediment particle size and NPART which is the incoming sediment particle class according to the USDA particle classes, all these parameters are shown in Table 13. The sediment properties are shown in Table 14 based on incoming sediment particle class.

Table 13: Input variables of incoming sediment properties

Input Parameter	Value	Unit	Source
Incoming Flow Sediment Concentration	0.034	(g/cm^3)-cl	Model default
Incoming Sediment particle class (NPART)	7	Unitless	Model default
Sediment particle size, diameter d50	0.0013	cm	Model default
Porosity of deposited sediment	0.46	fraction	Model manual
Portion of Particles from incoming sediment with diameter more than 0.00037 cm	0.5	Unitless	Model default
Sediment particle density (g/cm^3)	2.65	Unitless	Model default

Table 14*:* Incoming sediment properties based on incoming sediment particle class (NPART).

NPART	Particle class	Diam.range (cm)	d_p (cm)	V_f (cm/s)	S (cm^3/s)
1	Clay	<0.0002	0.0002	0.0004	2.60
2	Silt (type 1)	0.0002-0.0050	0.0010	0.0094	2.65
3	Small aggregate	N.A	0.0030	0.0408	1.80
4	Large aggregate	N.A	0.0300	3.0625	1.60
5	Sand	0.0050-0.2000	0.0200	3.7431	2.65
6	Silt (type 2)	0.0002-0.0050	0.0029	0.0076	2.65
7	User selected	N.A	later	model	SG

- ***Storm Hyetograph (irn)***

This project file needs the NRAIN, PEAK and RAIN(I,J) parameters which are defined in the model manual (Munoz et al., 2010). These parameters can be entered manually; however, it is recommended that the hyetograph is viewed by selecting the plot hyetograph button.

- ***VFS Source Area Storm Runoff (iro)***

The hydrograph is viewed by selecting the plot hydrograph button. Hydrograph and hyetograph which are the UH output, are used as VFSMOD inputs by browsing their files.

- ***VFS Water Quality Input File (iwq)***

Based on the manual, this file is only required when Water Quality Component or CWQ=1 in ikw. Since CWQ is equal to zero, there is no need to fill this project file.

CHAPTER 4: RESULTS AND DISCUSSION

In order to simulate the behavior of VFS in removing ARGs from runoff, the model was needed to be calibrated. Both the utility and the VFSMOD include input variables that could vary within a range of potential values.

4.1 UH utility calibration

The UH was calibrated by varying the curve number, d_p and crop factor (C). The curve number was varied in the range of 90 to 85, d_p between 300 to 4600 (µm) and C is in the range of 5 to 8 (Table 2-2a in model manual). The experimental data and summary of UH calibration for plot 701 Run 2 Rate 2 is shown in Table 15.

With a constant d_p and C the rainfall volume calculated by experimental data is like that obtained from model when curve number is equal to 87. As a result, for further simulations the curve number was chosen as 87. This value is in agreement with the recommended curve number by NRCS for the selected soil type and cover type. Since there is no change in rainfall volume by changing d_p and C, the average of d_p= 0.00202 cm and C equal to 5 were selected for calibration.

Table 15: UH calibration for rainfall hyetograph.

Calibration Run Number	Rainfall (mm)	Curve Number	dp (cm)	C	maximum rainfall predicted by model($m^3 \times 10^6$/s)	maximum rainfall - Experimental ($m^3 \times 10^6$/s)
1	177.3	90	0.00220	5	1227	532
2	177.3	89	0.00220	5	1544	532
3	177.3	88	0.00220	5	1056	532
4	**177.3**	**87**	**0.00220**	**5**	**538.57**	**532**
5	177.3	86	0.00220	5	1527	532
6	177.3	85	0.00220	5	892.57	532

4.2 VFS Calibration

Calibration was also performed on VFS inputs. The variables needed to be calibrated in VFS inputs are vertical saturated conductivity (k_s), average suction at the wetting front (S_{av}), grass manning roughness, bare surface manning and porosity. Depending on the soil type, the manual of the model defines values for the Green Ampt parameters. These parameters are taken from the Green-Ampt (G-A) infiltration model (i.e., the G-A model) which is often used to characterize the infiltration process in hydrology (Xiang et al., 2016). Although the soil type used in the project was silty clay loam, the "Silty Clay" and "Sandy Clay Loam" and "Clay" types were also considered for the calibration. This can provide useful information regarding the effect of different soil properties on the filter efficiency. Among the model outputs (i.e., Sediment Delivery Ratio or SDR, runoff volume and infiltration volume), SDR and the runoff volume could be compared to their counterpart values calculated by experimental data.

The experimental results include SDR, runoff volume and infiltration volume. SDR was chosen as the calibration factor as both variables needed to calculate SDR, are included in the experimental Equation 2 shows the definition of experimental SDR. Sediment exiting the filter is shown in the experimental data as "erosion" and sediment entering the filter is shown as "soil loss". For plot 701-Rate2-Run2, the values of both parameters are taken from experimental data and shown in Table 16.

$$SDR = \frac{\text{(mass of sediment exiting the filter)}}{\text{(mass of sediment entering the filter)}} \qquad \textbf{Equation 2}$$

Table 16: SDR calculation based on experimental data for plot 701-rate2-run2.

Parameter	**Value**
Storm duration (min)	30
Erosion (kg/ha)	67
Soil loss (kg/ha)	188
SDR%	**35.65**

As shown in Figure 6, the outputs related to silty clay loam did not match with the experimental SDR. The soil type in the project is silty clay loam. After model calibration, the VFSMOD underpredicts the SDR or overpredicts the sediment trapping efficiency. The predicted values and the experimental ones are in a good agreement if the soil type is chosen as sandy instead of silty clay loam. Sandy soil has higher saturated hydraulic conductivity compared to silty clay loam. The higher conductivity leads to higher SDR or lower trapping efficiency. It shows that in order to increase the efficiency of a filter strip it is better to use a soil with lower saturated hydraulic conductivity such as silty clay loam or clay.

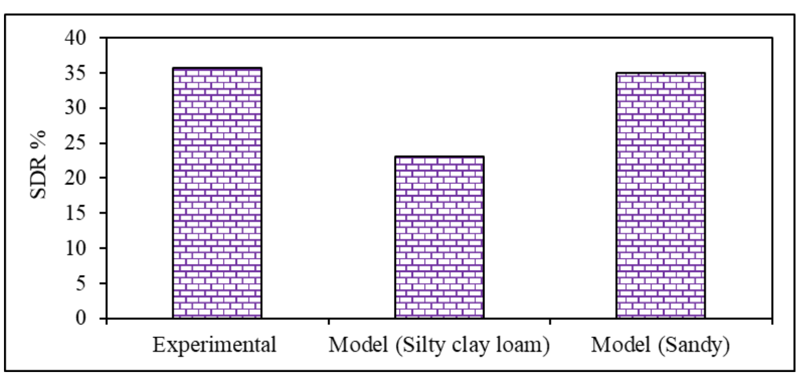

Figure 6: Experimental SDR and model SDR for silty clay loam and sandy soil.

The calculated results of SDR best matched with the experimental results when the soil type is Sandy with K_s=66.5×10^{-6} m/s, S_{av}=0.042 m, Bare Clay Loam=0.012 $ms^{-1/3}$ and Grass Manning Roughness= 0.39 $mS^{-1/3}$. As a result, after calibration, all UH outputs were changed based on sandy soil variables shown in Table 17.

Table 17: Updated UH inputs for sandy soil.

Curve number	d_p (cm)	Crop factor	maximum rainfall predicted by model(m^3×10^6/s)	maximum rainfall - Experimental (m^3×10^6/s)
85	0.042	8	618	532

The calibration results showed that the SDR decreases with decreasing hydraulic conductivity (K_s). Ks is defined as the ease with which the saturated soil pores permit the water movement. Higher SDR value (lower trapping efficiency) might happen due to the fact that water cannot penetrate to the soil pores and as a result moves on the soil surface as runoff. The results were in a good agreement with the fact that filter trapping efficiency is dependent on the soil hydraulic properties. The outputs of the calibrated model are presented in Figure 7 and Figure 8.

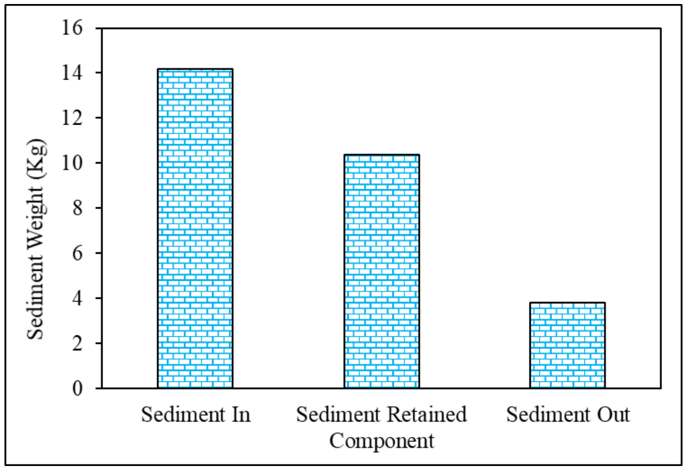

Figure 7: Mass of sediment in and sediment out for plot 701-2-2. .

As Figure 7 depicts, about 65% of total sediment was retained by the grass hedges. The remaining weight is the sediment moved out of the filter. The SDR (i.e., ratio of sediment out to sediment in) is found to be equal to 35%.

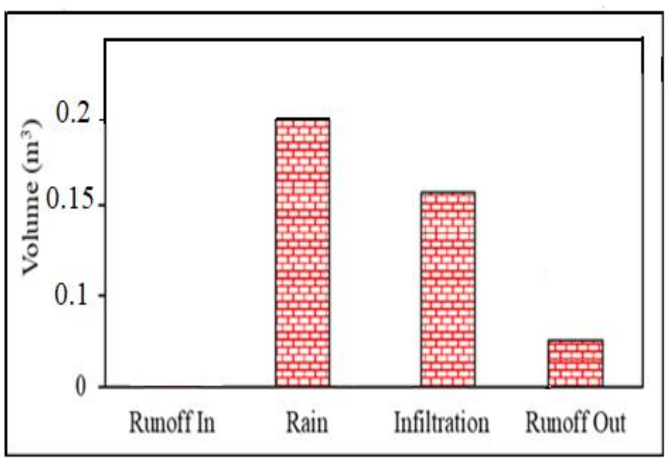

Figure 8: Runoff in, out and infiltration (m^3) for plot 701-2-2.

Figure 8 shows the second output of the model which is a mass balance of the runoff entering the filter, rainfall, infiltration and the runoff exiting the filter. These volumes will be used to calculate the concentration of tylosin and ARGs which leave the filter. Table 18 shows the output values of the model for plot 701-run2-rate2 plus SDR value defined as the ratio of mass of sediment out to the mass of sediment in.

Table 18: Model output values for plot 701-Rate2-Run2.

Parameter	**Value**
Sediment in (kg)	13.65
Sediment retained (kg)	8.88
Sediment out (kg)	4.77
SDR%	**35**
Runoff in (m^3)	0.40
Rain (m^3)	0.19
Infiltration (m^3)	0.12
Runoff out (m^3)	0.47

The SDR measured by the model is in a good agreement with the SDR calculated based on experimental data for all of filters with different flow rates. As a result, VFSMOD can predict the behavior of the same VFSs in ARG removal.

4.3 Design Procedure

The design aims to find an optimum value for the filter length and also proper soil type to produce low runoff volume. RDR or runoff delivery ratio is defined as runoff exiting the filter divided by runoff entering the filter. The calibrated VFSMOD is used to predict the concentration of ARGs in runoff coming out of narrow grass hedge in the same project. It should be noted that runoff volume is calculated instead of SDR since the concentration of

ARGs can be defined by multiplying this volume to the copies of genes. The plot length and soil type should be varied to investigate the effect of these variables on the volumes of runoff accurately. To this end, the plot length is changed, and the soil type is assumed to be unchanged and then the type of soil is altered, and length of the plot remains fixed. Figure 9 and Figure 10 show how the plot length changes the amount of tylosin and ARGs in runoff for sandy soil.

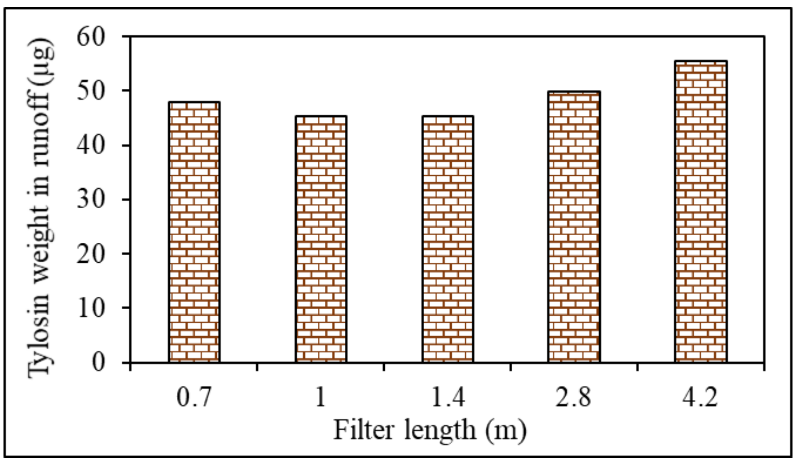

Figure 9: Amount of tylosin in runoff vs different filter lengths.

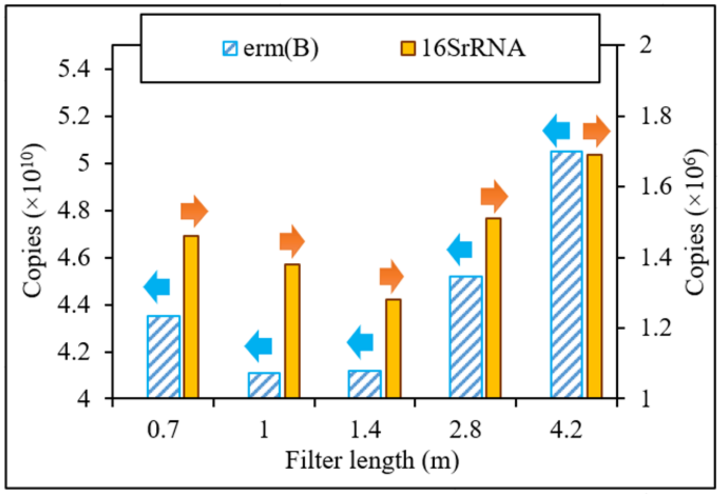

Figure 10: Copies of erm(B) and 16SrRNA genes vs filter length.

As Table 19 and Figure 11 present the minimum concentration of ARGs is for plot length equal to 1 m. The concentrations increase in lower and higher filter length. It reveals that there is an optimum filter length in which filter has the highest trapping efficiency. Increasing the filter length results improving infiltration by decreasing flow velocity. However, increasing the length more than the optimum value will cause concentrated flows in which the filter will work ineffectively. The best performance of the filters occurs when there is a shallow water and not concentrated flow. Some studies concluded that increasing flow length beyond the optimum does not increase VFS efficiency (Lee et al., 2003; Zreig et al., 2004). They concluded that the first 5m of VFS play a significant role in removing suspended solids and aggregates larger than 40 mm. But longer filters were not that much effective. Dillaha et al., (1989) showed that doubling the filter length from 4.6 m to 9.1 m decreased trapping efficiency by an additional 10, 12 and 23% for three different plots respectively.

After finding the optimum length of the plot, the model is used to simulate the effect of other soil types on optimum plot length. Table 18 and Figure 11 present the runoff volumes for three different soil types in the optimum plot length.

Table 19: ARGs concentration in runoff for different soil types.

Soil Type	Runoff Volume (m^3)	Tylosin (μg)
Clay	0.558	0.715
Silty Clay	0.549	0.698
Sandy	0.378	0.4524

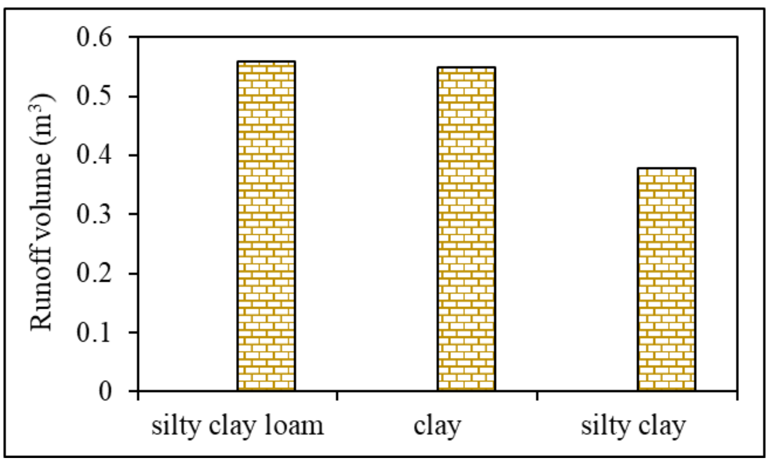

Figure 11: Runoff volume for different soil types.

As shown in Table 19, the sandy soil has the minimum mass of tylosin, showing the highest trapping efficiency of the filter. Among three soil types shown in Table 19, sandy has the highest Ks, which is considered as a critical factor in determining SDR. Besides it was shown that different Ks results in different pollutant concentration or trapping efficiency. As a result the suitable soil type for establishing NGH for ARGs is chosen as sandy soil.

CHAPTER 5: CONCLUSIONS AND RECOMENDATIONS

5-1 Summary and Conclusions

In this study VFSMOD was used to simulate the behavior of VFS in removing ARGs. The model was applied to a site located in Lincoln Nebraska with corn crop and silty clay loam soil. VFSMOD was first calibrated to show promising result compared to the experimental values. The simulation shows that the filter efficiency in removing ARGs is different for different soil types and filter lengths. There is an optimum length for the filter strip that produces minimum runoff volume. Based on the model results increasing the length of the filter by 1-meter leads to higher efficiency but widening beyond that decreases the efficiency. The VFSMOD which was proved to work well in estimation of VFS trapping efficiency shows confirming results for ARG. The removal of emerging contaminants such as ARGs was not studied as much as other contaminants like sediments and nutrients.

5-2 Suggestions for Future Research

Although the results of this study are satisfying and similar to the experimental results, it is better to include the experimental data in future studies more accurately. One limitation of this study is low experimental data needed by the model where assumed as default. In order to find more trustable results model inputs must be taken from the experimental data unless it was not accessible Based on the findings of this study one step can be taken to expand current conclusions. Removal of other ARGs which are not included in this study are highly recommended since they are commonly found in agricultural manures.

REFERENCES

- Bair, D. A., Popova, I. E., Tate, K. W., & Parikh, S. J. (2017). Transport of oxytetracycline, chlortetracycline, and ivermectin in surface runoff from irrigated pasture. Journal of Environmental Science and Health, Part B, 52(9), 631-640.
- Cahill, M., Godwin D.C., Sowles, M. (2008), Vegetated Filter Strips. Low Impact Development: Fact Sheet, Oregan Sea Grant Corvillis, Oregon, ORESU-G-11-003.
- Deletic, A. (2001). Modelling of water and sediment transport over grassed areas. Journal of Hydrology, 248(1-4), 168-182.
- Dosskey, M. G., Helmers, M. J., & Eisenhauer, D. E. (2011). A design aid for sizing filter strips using buffer area ratio. Journal of soil and water conservation, 66(1), 29-39.
- Gilley, John E., Bartelt-Hunt, Shannon L., Lamb, Seth J., Li, Xu., Marx, David B., Snow, Daniel D., Parker, David B., Woodbury Bryan L. (2013). Narrow grass hedge effects on nutrient transport following swine slurry application. Transactions of the ASABE, 56(4), 1441-1450.
- Grismer, Mark E., O'Geen, Anthony T., Lewis, David., (2006). Vegetative Filter Strips for Nonpoint Source Pollution Control in Agriculture. Publication 8195.
- Helmers, M. J., Isenhart, T. M., Dosskey, M. G., Dabney, S. M., & Strock, J. S. (2008). Buffers and vegetative filter strips.
- Harner, J. P., Murphy, J. P., Delvin, D. L., Fick, W. H., & Kilgore, G. L. (2000). Vegetative filter strip systems for animal feeding operations. Kansas State University–Research and Extension. MF-2454.

- Hussein, J., Ghadiri, H., Yu, B., & Rose, C. (2007). Sediment retention by a stiff grass hedge under subcritical flow conditions. Soil Science Society of America Journal, 71(5), 1516-1523.
- Khatavkar, P. N. (2015). Optimization model for design of vegetative filter strips for stormwater management and sediment control. Arizona State University.
- Lin, C. H., Lerch, R. N., Garrett, H. E., Gantzer, C. J., Anderson, S. H., & George, M. F. (2007, June). Utilizing vegetative buffer strips to remove dissolved and sediment-bound atrazine, metolachlor and glyphosate from surface water runoff. In Proceedings of the 10th North American agroforestry conference, Quebec (pp. 113-121).
- Lin, C. H., Lerch, R. N., Goyne, K. W., & Garrett, H. E. (2011). Reducing herbicides and veterinary antibiotics losses from agroecosystems using vegetative buffers. Journal of environmental quality, 40(3), 791-799.
- Meyer, L. D., Dabney, S. M., & Harmon, W. C. (1995). Sediment-trapping effectiveness of stiff-grass hedges. Transactions of the ASAE, 38(3), 809-815.
- Minnesota Legislative Reference Library: https://www.leg.state.mn.us/lrl/sonar/sonar, last access: November 2018.
- Munoz-Carpena, Rafael., Parsons, John E. (2010). VFSMOD-W Vegetative Filter Strips Modelling System; Model Documentation and User’s Manual.
- Southeast Michigan Council of Governments. (2008). Low Impact Development Manual for Michigan: A design guide for implementers and reviewers. Detroit, MI.
- Owino, J. O., Owido, S. F. O., & Chemelil, M. C. (2006). Nutrients in runoff from a clay loam soil protected by narrow grass strips. Soil and Tillage Research, 88(1-2), 116-122.

- Parajuli, P. B., Mankin, K. R., & Barnes, P. L. (2008). Applicability of targeting vegetative filter strips to abate fecal bacteria and sediment yield using SWAT. Agricultural water management, 95(10), 1189-1200.
- Rahman, S., Rahman, A., & Wiederholt, R. J. (2011). Vegetative Filter Strips Reduce Feedlot Runoff Pollutants. NDSU Extension Service, North Dakota State University.
- Sabbagh, G. J., Fox, G. A., Kamanzi, A., Roepke, B., & Tang, J. Z. (2009). Effectiveness of vegetative filter strips in reducing pesticide loading: Quantifying pesticide trapping efficiency. Journal of Environmental Quality, 38(2), 762-771.
- Soni, B., Bartelt-Hunt, S. L., Snow, D. D., Gilley, J. E., Woodbury, B. L., Marx, D. B., & Li, X. (2015). Narrow grass hedges reduce tylosin and associated antimicrobial resistance genes in agricultural runoff. Journal of environmental quality, 44(3), 895-902.
- Sudhishri, S., Dass, A., & Lenka, N. K. (2008). Efficacy of vegetative barriers for rehabilitation of degraded hill slopes in eastern India. Soil and Tillage Research, 99(1), 98-107.
- Wu, L., Munoz-Carpena, R., and Li, Y. (2015). Vegetative Filter Strips _ A Best Management Practice for Controlling Nonpoint Source Pollution. University of Florida, UF/IFAS Extension: SL432.
- Zuazo, V. H. D., Pleguezuelo, C. R. R., Flanagan, D. C., Martínez, J. R. F., & Raya, A. M. (2009). Agricultural runoff: new research trends. Agricultural Runoff, Coastal Engineering, and Flooding, 27-48.
- United States Department of Agriculture, Participation of Historically Underserved Producers in USDA Conservation Programs and NRCS Support for Hispanics in

Agriculture,https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/econ/data/?cid=nrcs143_009665, last access: November 2001.

- United States Environmental Protection Agency (EPA), http://www.epa.gov/OWOW/NPS/MMGI/Chapter7/index.html, last access: November 2018.
- USDA-NRCS; 210-VI-TR-55, 2nd Edition, June 1986.